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In the sections that follow, the experience of several Western European countries in the handling, treatment, and disposal of liquid radioactive wastes is reviewed. The information presented was obtained while visiting in these countries during the period September 9 to October 11, 1957.

United Kingdom

Routine liquid radioactive wastes are treated at Harwell by the addition of caustic soda to raise the pH to 9.5 to 10, of 50 to 100 ppm of PO_4^{-3}, and of acid to lower the pH to 7 to 7.5. By this treatment about 90 per cent of the alpha activity and 60 to 85 per cent of the beta activity is removed. If alpha activity is high, it can be reduced to background by acidification with H_2SO_4 to pH 3 followed by the addition of 10 ppm analytical grade tannic acid. The pH is then raised to 9 with lime, 100 ppm PO_4^{-3} is added, and the precipitate removed in upflow (sludge blanket) type units. To improve operation, the calcium phosphate floc is being weighted with about 3 ppm $Fe(PO_4)\cdot 2H_2O$.

As a second step in the treatment process for low level wastes, the upflow effluents are passed through vermiculite columns. If the total decontamination obtained is insufficient to allow discharge to the

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Thames River, the effluent may be returned for retreatment or it may be stored and released following dilution with less active wastes.

The chemical sludges or precipitates are dewatered presently by freezing. This method, originally developed for dewatering organic type sludges, e.g., sewage sludge, was tried with the crystalline chemical sludges and found to work well. The radioactive sludges are frozen by means of conventional units, thawed, and immediately dewatered. Prolonged standing after thawing or mixing vitiate the dewatering benefits of freezing.

Following dewatering, the sludges are placed in drums, and hauled every six weeks or so to the east coast of England for disposal off the Channel Islands in water 65 fathoms deep. During transit, the transport is accompanied by laboratory personnel. Radiation levels on the surface of the drums shall not exceed 2 M. P. L. (1 M. P. L. = 0.3 r per week), except that not more than 10 per cent of the drums may have a radiation exposure of 10 M. P. L. at the surface.

Small containers of higher activity liquid waste are placed in small drums of five-gallon size, broken and the liquid taken up in lime, placed in a larger container, shielded with concrete to the exposure levels indicated earlier, and disposed of in the English Channel. Some shipments are also disposed of in the Atlantic Ocean, but at depths of 2,000 fathoms.

Intermediate level wastes are batch-treated by phosphate coagulation, as described, until suitable for discharge to the Thames River. Higher

level wastes, on the other hand, go to a separate treatment plant, where special precipitation techniques are provided. The sludge is handled as described, and the filtrate passes to an evaporator.

A more extensive system of waste treatment for low level wastes has been suggested by Dr. Amphlett, and is directed to the reuse of effluent as process water. The procedure involves three stages of treatment, namely: (1) flocculation with lime, phosphate, and iron, (2) passage through vermiculite beds, and (3) deionization in an electrolytic ion exchange unit. The effluent from this plant will approach deionized water and will be reused in many laboratory operations presently utilizing mixed bed deionized water. By such a recycling system, the total quantity of water required would be reduced, thus cutting down the cost of deionized water and resulting in a much smaller discharge of liquid wastes from the Harwell establishment.

The sludge from the flocculation treatment will be dewatered, with return of filtrate to the flocculation units, and will be combined with other solid wastes for further processing to fix the activity by heat treatment. After firing and fixation, the unleachable solid wastes would be stored at some suitable location.

High level laboratory wastes will be collected in separate containers, evaporated or subjected to a precipitation process as required. If evaporation is used, the condensate will be mixed with other low level wastes and go through the treatment process described earlier. The chemical sludges, produced during the precipitation step, will be mixed with

solids coming from the low level flocculation plant. Following the addition of silica, fluxes, etc., the material will be fired and the unleachable solids will be stored.

This three-step treatment process is expected to provide a decontamination of about 10^3 to 10^4. The volume of wastes to be handled will amount to approximately 500,000 gallons (Imperial) per day.

An interesting observation made by Dr. Amphlett concerned the selective retention of strontium over cesium by the vermiculite they studied. Some preliminary results indicated that the cesium broke through the columns after a throughput of about 50 volumes, whereas the strontium required about 700 volumes.

At Windscale, wastes other than those obtained from direct reprocessing of fuel, are neutralized before passing to holding tanks. Alum is added and the wastes are passed through sludge blanket units. By such treatment about 80 to 90 per cent of the beta activity is removed. The basic problem here is the removal of ruthenium since it controls the amounts of waste that may be discharged into the Irish Sea off the coast of England. As many of you know, the ruthenium in the waste is adsorbed on a fine ribbon type of seaweed - Porphyra umbilicalis. This seaweed, which is used by the Welsh for making a black glutinous product called laverbread, is about one cell thick with an enormous surface area.

Studies are under way to find methods that may be used to complex the ruthenium, thus preventing its uptake on the fine iron particles

which are present in the sands of this area. It has been found that these ruthenium coated particles accumulate in the gills of marine forms and that the gills are cleansed of the particles when they are placed in clean water.

About 1-1/2 mc/month of radium and some uranium is discharged along with the effluent from Springfields where uranium metal is purified and fuel elements are fabricated. The wastes are discharged to the estuary and are not treated as a serious problem. Almost all measurements of activity are made on muds, since these materials accumulate there.

Denmark

Denmark has a 5W Water Boiler Reactor from Atomics International, which is located at Riso on a peninsula about 30 kilometers west of Copenhagen. A plant is under construction at the site to concentrate, by evaporation, the small amounts of waste being produced. The evaporator concentrates will be mixed with concrete and placed in drums for above ground storage. At present the waste volume is very small coming from low level laboratories, from semihot cells where work is carried out at 10-20 mc levels, and from hot cells which process experimental fuel element types tested in the reactor.

There are no regulations relating to the discharge of low levels of activity from hospitals and other sources using radioisotopes. In general, water dilution is provided and the spent isotopes are discharged to the sewer. Urine containing radioactive iodine, for example, is collected separately, monitored, stored for 4 or 5 days, and stable sodium iodide is added before discharge.

Norway

The Joint Establishment of Nuclear Energy Research (JENER) is located at Lillestrom, some 15 miles east of Oslo. Here, the JEEP reactor went critical in July 1951. It is of the CP-3 type fueled with natural uranium, cooled, and moderated with heavy water. Operating at 450 to 500 kw with a neutron flux of 10^{12} neutrons/cm^2, it is used for physics experiments, neutron spectroscopy, and isotope production. The bulk of the wastes produced come from isotope separations, although other fission product wastes are produced from fuel dissolution which is practiced on a very small scale, primarily for experimental purposes.

Iodine-131 containing waste from chemical separations is stored and controlled quantities are released to the river. The Establishment would like to have levels of discharge established similar to those used at Harwell for release of activity into a stream environment. Plans are under way to provide a waste treatment and disposal facility on site for treating low level wastes produced in the isotope building, metallurgical and chemical hot cells, and in the existing chemical building. About 23 m^3/ day will be treated in a plant providing facilities for the addition of Ca^{++} to raise the pH in the first upflow unit, followed by NaOH and PO_4^{-3} in the second upflow unit. The chemically treated effluent then passes through a two-stage filtration unit with anthrafilt in the first stage and vermiculite in the second stage. The sludges produced will be stored in drums and held until permission is granted for sea disposal. At the proposed levels of operation, it is estimated that three 250 liter drums of sludge will be produced per month for disposal.

Sweden

The Swedish Atomic Energy Company has under construction a reactor and atomic energy research station at Studsvik, about 45 miles south of Stockholm on the eastern coast. Considerable study has been given to the kinds and quantities of wastes that may be produced at this site. These wastes have been categorized into 8 groups, four of which will be radioactive, as shown in Table I.

Category I wastes from the first separation column will be stored in acid proof steel tanks in underground rock excavations following evaporation. The condensate will be combined with Category III wastes.

Category II wastes include the 2nd and 3rd cycle raffinates. These wastes will go to steel tanks for monitoring, followed by evaporation and storage of concentrate. The condensate will be combined with Category III waste. The more active wastes from Category III would be bypassed directly and combined with Category II wastes for treatment by evaporation.

Category III includes wastes from hot laboratories, condensate from Categories I and II, and all other active wastes. This category is connected with the chemical treatment plant or evaporator. If, after monitoring, the effluent or condensate activity is low enough, the waste will be discharged into the channel between Stora Bergo and Studsviksholme. The evaporator concentrate will be added to the Category II concentrate storage facility. Present thinking with regard to this category of waste is that aluminum hydroxide, ferrous sulfate, and tri sodium phosphate may be used as coagulants, following in general British practice at Harwell,

Table I: Estimated Daily Quantity and

Activity of Liquid Wastes

	Category of Waste	Activity	Quantity m^3/day
I	1st Cycle Raffinate (Plutonium seperation plant) (Plutonium 2nd and 3rd cycle)	15kc	1.3
II	2nd and 3rd Cycle Raffinate	15-30c	20
III	Active Laboratory Wastes (Research Laboratories)		
IV	Outlet Water (Miscellaneous Wastes)	0-15c	100
V	Cooling Water and Fire Extinguishing Water		
	-- Fresh Water		100
	-- Salt Water		105,000
VI	Sewage		275
VII	Water from Areas Surrounding Active Buildings - 1.2 inch rain		660
VIII	Water from Non-Active Areas		---

with filtration of the clarified effluent through sand and vermiculite beds. From 67 to 90 per cent of the radioactivity may be removed and provision will be made for recirculation as needed. The low level sludge will be dewatered and buried on site. Ion exchange facilities will be provided for use in case of emergency or unusual peak loadings.

The wastes comprising Categories IV, V, VI, VII, and VIII are grouped as being nonactive wastes. However, if activity above prescribed levels is found in these wastes, they will be combined with Category III wastes and treated as already indicated. After monitoring, these waste streams will be discharged into Lake Tveren.

France

The treatment of low level liquid radioactive wastes at Saclay follows British practice very closely. Phosphate coagulation is utilized with 100 ppm phosphate and 100 ppm tannin added. It is claimed that the tannin speeds up flocculation and is helpful in the removal of strontium. The calcium phosphate precipitation at a pH of about 11 to 12 results in a volume reduction of about 50, produces a sludge having a moisture content of about 99 per cent, and provides a decontamination factor of about 25.

A truck is used to haul the decontaminated liquid to Chatillon, located about 15 km from Saclay, where it is discharged into the sewerage system for treatment with Paris sewage before release to the Seine River.

The sludge is dewatered, placed in 55-gallon steel barrels, and stored above ground in a building located near the treatment plant.

At the reactor site at Marcoule, it is expected that about 200 m^3 of acidic waste (pH - 0.5) will be produced daily having an activity level ranging from 1 to 3 c/m^3. High level wastes will amount to 5 to 50 m^3/yr, depending on the composition of fuel elements processed. The low value is for processing natural uranium and the upper value for processing alloyed fuel elements. These wastes will be evaporated to an activity level of something in the order of 500 curies/liter, varying from 200 to 1,000 curies per liter.

Special treatment is being considered for the intermediate level wastes because the radiochemical composition is quite uniform. The studies outlined include the following: (1) different phosphate treatments, (2) influence of neutralizing agent, (3) acid treatment, (4) adsorption in acidic form on metallic powders, (5) improved decontamination of cesium, and (6) adsorption in alkaline pH after chemical treatment.

For high level waste treatment formation of glass is the first consideration, followed by ceramic formation. Calcination may be studied in the future. With regard to ultimate disposal of wastes, contracts have been made with other governmental agencies to study the possibilities of underground discharge or sea disposal. The initial studies are being carried out to evaluate the possibilities of releasing low level wastes and contaminated sludges into either of these two media.

Netherlands

Because of ground water conditions in the Netherlands, it is impossible to consider disposal of radioactive wastes into the ground.

Accordingly, present thinking is concerned with the possibilities of utilising evaporation even for low level waste treatment, with storage of the solids in containers above ground until such time as new disposal is resolved.

Considerable progress has been made in the Netherlands in the possible application of electrodialysis for desalting sea water. There is some interest, therefore, in the use of this meth[illegible]or the removal of ionic constituents from liquid radioactive wastes.

Belgium

The Belgian atomic energy facilities are located at Mol. Liquid radioactive wastes cannot be discharged into a canal flowing by the plant site to Antwerp. The wastes are pumped to the River Mol Bethe which has a flow of 50,000 m^3/day. The permissible amounts of radioactive materials that may be discharged have been established by the Ministry of Health and follow British practice. On this basis, about 8 mc of activity may be discharged daily, but it is felt that these levels will have to be increased to 50 to 100 mc/day. This may be possible without exceeding permissible levels, because it is stated that there is considerable error in estimating the flow of the river. (The levels are based on a flow of 8,000 m^3/day when the actual flow is 50,000 m^3/day).

Treatment of the low level wastes follows British practice, in general, at least insofar as chemical treatment is concerned. However, instead of passing the chemical effluent through vermiculite, it is passed

through columns of sawdust, either fresh or rotted. The claim is made that sawdust has the added advantage of being incinerateble, thus reducing the amount of material that has to be disposed of by burial either on land or in the sea. More recently, brown coal or lignite is being studied for use in place of the sawdust.

De Jonghe divides the wastes to be treated at Mol into three categories as follows:

(1) Cold water - activity level about drinking water tolerance or about 10^{-6} uc/ml. This waste consists of sewage, cooling water, and water from non-radioactive laboratories. At present it amounts to about 200 m^3/day, but it is expected to increase to about 600 m^3/day. Treatment consists of neutralization with CaO (sometimes with $Al_2(SO_4)_3 \cdot 8H_2O$) followed by passage through trickling filters. Gross beta-gamma activity reductions of about 65 per cent are expected. The trickling filter effluent has a B.O.D. of 18 ppm.

(2) "Tiede" or intermediate level wastes - activity level about 10^{-3} uc/ml. This waste comes from all active laboratory areas; cleaning, rinse, and tracer discharges; and the discharge from the reactor canal. It amounts to 30 m^3/day. The final treatment plant to process these wastes has not been completed, but a pilot plant capable of treating up to 10 m^3/day is in use. Treatment includes calcium phosphate precipitation, iron salt precipitation, and brown coal filtration. A decontamination factor of 50 is obtained. There is considerable concern over the the excess use of Versene and other complexing agents which interfere with the operation of the treatment plant.

(3) Hot wastes - activity level about 1 uc/ml. Nothing has been done in the way of specifying treatment for these wastes. For the present, they are stored. On the one hand, consideration is being given to evaporation as a treatment scheme, and on the other hand, either ordinary chemical treatment or specific chemical treatment is being investigated.

With the location of the OEEC (Organization of Economic European Cooperation) chemical processing plant at Mol, provision will have to be made for handling reprocessing wastes. DeJonghe feels that ideas other than evaporation should be considered when plans are made for treating these reprocessing wastes.

Germany

The extensive use of ground water for water supply purposes precludes utilization of the ground as a means of disposal for liquid radioactive wastes. Furthermore, permission has not been granted by the Ministry of Health to discharge any radioactive materials into surface waters. These two factors restrict the release of any radioactive materials into the environment. As a result, German thinking with regard to radioactive waste disposal is essentially containment at the site either in liquid or solid form.

In the first German reactor, a light water moderated swimming pool reactor located at Garching 15 km north of Munich, deionized water is used as the coolant in the primary circuit and ground water in the secondary circuit. Any radioactive materials in the primary coolant will be removed when the coolant is passed through mixed bed ion exchange resins. Open

basins are provided for the storage of other wastes. These wastes will be monitored and, if found inactive, will be discharged to a small stream (flow 2 m^3/sec) located at the site.

Acknowledgement

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